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REVEGETATION OF CARBONATE MINES IN SOUTHERN CALIFORNIA

Supplement No 2.

REVEGETATION OF CARBONATE MINES IN SOUTHERN CALIFORNIA

A Report Prepared

for the

U. S. Forest Service

June, 1981

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INTRODUCTION

Revegetation of mined areas has received increased attention in recent years because of Federally mandated reclamation and increased focus on mineral exploration and mining. Schaller and Sutton (1978) and Vories (1976) have addressed many of the problems associated with the reclamation of drastically disturbed lands. Little detailed information is available, however, on mechanisms for revegetation of western surface mined sites other coal. Much valuable information has been compiled by the Forest Service, Surface Environment and Mining program (1980 a, b, c, d, e). Extensive areas have been exposed by surface mining of calcium carbonate rock in southern California's transverse mountain ranges. The purpose of this study was to select plant material and to explore ways of establishing plants and modifying site characteristics to maximize growth on abandoned carbonate mined sites at 2380 m on the north slope of the San Bernardino Mountains, California.

Calcium carbonate is a common component of soils in arid regions. Calcium is an essential element for plants but in excess it may destroy roots, shoot apices, and reduce growth. In less toxic concentrations, calcium brings about deficiencies of iron, magnesium, potassium and phosphorus (Stalfelt, 1972). In arid and semi-arid regions, the majority of plants are indifferent to calcium because it is usually present in large amounts and soils are mostly neutral or alkaline. In this condition most Ca is rendered unavailable. However, more acid conditions release calcium to potentially toxic levels.

Earlier studies on carbonate mine reclamation at a lower elevation (1550 m) showed that certain native arid land plants could

survive in calcium carbonate mine spoil (Burk and Hanes, 1978). Those studies revealed that applications of pulverized redwood bark to the substrate inhibited growth of seedlings. They speculated that increased chemical breakdown of the substrate caused by decreased pH and associated calcium imbalance or lack of water to sufficiently wet the resulting soil mixture may have been responsible. Best results were obtained with added water and fertilizer.

EXPERIMENTAL PLOTS

Study Site

The experiments described here were conducted on an abandoned carbonate mine spoil at 2380 m on the upper north slope of the San Bernardino Mountains near Holcomb Valley (T3N, R1W, S24; Lucerne Valley Quadrangle), California. The study site consisted of a series of terraces formed by depositing spoil that stabilized on an approximately 1:1 slope. Records are incomplete as to when the terraces were formed. The best estimates of the miners in the area suggest that they have been there at least 10 years.

Vegetation on the terraces and terrace slopes is limited to marginal areas where some soil mixing can be assumed and where seed sources are available. The principle species that have established naturally include Penstemon grinnellii (Grinnell penstemon), Chrysothamnus parryi (Parry rabbitbrush) and Cercocarpus ledifolius (curlleaf mountain mahogany).

The vegetation on surrounding undisturbed hillsides is transitional between the desert chaparral and pinyon-uniper woodland vegetation types described by Horton (1960). The general physiognomy is of small trees of Abies concolor (white fir), Pinus monophylla (pinyon), Juniperus californica (California juniper), and Quercus

chrysolepis (canyon live oak), interspaced with large shrubs of Fremontodendron californica (flannel bush), Ceanothus greggi (Gregg ceanothus), and Cercocarpus ledifolius (curlleaf mountain mahogany). The plants are widely spaced and bare ground is easily visible from a distance.

The soils at the site are derived from the Paleozoic Furnace Formation composed of sediments from an ancient seaway metamorphosed to limestone-white and blue-gray, massive and thin bedded, calcite and dolomite marble. Soil pH is near neutral ranging from 7.2 to 7.8. The chemical constituents of the soil are listed in Table 1. The particle size changed from site to site with surface material ranging from 5-10 cm boulders to a mixture of silt, sand, and gravel sized particles. The material is mechanically fractured with the resulting sharp edges and flat faces on particles.

Experimental Design

Experimental plots (1 x 13 m) were established parallel to the slope of the terraces. In 1979, one terrace had 21 experimental plots and the terrace immediately below had 28 experimental plots. Experimental manipulations were applied to groups of 7 plots each in the following manner: 1) control plots, 2) only slow release fertilizer (osmocote) added, 3) only straw mulch added, 4) slow release fertilizer and straw mulch added, 5) water and slow release fertilizer added, 6) water and straw mulch added, and 7) water, slow release fertilizer and straw mulch added. The following year (1980) 30 additional plots were added in groups of 6 to the upper and lower terraces. Manipulations on the lower terrace were 1) control plots, 2) only mulch added, 3) only slow release fertilizer added, 4) slow

Table 1. Means and standard deviations for selected soil properties from 11 samples taken from and near the experimental carbonate mine revegetation plots. Nutrient values are in parts per million air dry soil or (*) saturation extract.

Soil property	Mean	s
pH	7.5	0.2
Electrical Conductance (EC x 10^3)	0.4	0.1
Nitrate nitrogen	3.6	1.2
Sulfate Sulfur	< 5	
Potassium	109.5	64.3
Phosphate Phosphorus	6.1	1.9
Iron	6.1	3.1
Zinc	4.4	1.2
Copper	1.4	0.4
Manganese	5.9	3.4
Sodium*	7.6	10.1
Calcium*	111.3	77.4
Magnesium*	15.0	4.7

release fertilizer and mulch added, and 5) Agriform, forest starter fertilizer tablets added with containerized plantings. Upper terrace plots were identical with the exception of one additional watering 2 weeks after planting.

Mulch plots were covered with 2-5 cm of barley straw held in place with chicken wire fastened to the slopes with reinforcing rods. Distribution of mulch was not uniform because of wind shift, even under the wire. The lack of fine particles near the surface in some areas made the binding of mulch by forcing it into the surface with machines not feasible.

Slow release (12-14 mo) fertilizer (18-5-11) beads were added to appropriate plots by hand at a rate of 1.5 kg/m^2. Where large rocks were near the surface, the fertilizer fell between them and was not visible from the surface. On slopes with fine particles near the surface, 10-20 cm contour terraces were constructed by hand prior to fertilizer application. This prevented the beads from rolling down the slope and allowed raking of fertilizer beads into the terrace.

The fertilizer tablets (9 gm) utilized in some plots in spring 1980 were 22-8-2 NPK. These were inserted in the bottom of the planting hole before placing the plant.

Water was applied to all plots at planting time (22 June 1979; 22, 23 May 1980) by hand sprayer from a water truck. During 1979, water was applied monthly through October to the appropriate plots and in 1980 the watered plots only received a single additional watering 2 weeks after planting. Distribution was somewhat uneven because of the application method but water was applied to approximate 2.5 to 4 cm of rainfall at each application. Watering

was to continue during the summer of 1980, however, this was prevented by communication problems with the contractor.

Plant Materials

The first plantings were made with seed on 22 June 1979. The 7 seed plots within each treatment were as follows: 1) Purshia glandulosa, 2) Chrysothamnus nauseous, 3) Eurotia lanata, 4) Eriogonum fasciculatum, 5) Atriplex canescens, 6) mixed shrubby composites, and 7) control plots without added seed.

Spring plantings of 1980 were made on 22, 23 May, approximately 1 mo earlier than in 1979. The 6 experimental plots in each treatment were divided in half with the upper portion of the slope receiving containerized plants and the lower portion seeds. Materials planted were: 1) Cercocarpus ledifolius plants and seeds, 2) Atriplex canescens plants and seeds, 3) Purshia glandulosa plants and seeds, 4) Artemisia tridentata plants, 5) Eriogonum fasciculatum plants, 6) Chrysothamnus nauseosus plants, 7) Penstemon grinnellii seeds, 8) Fremontodendron californica seeds, and 9) Ceanothus greggii seeds.

The Cercocarpus, Purshia, Artemisia, and Chrysothamnus plants were purchased from Native Plants, Inc., Salt Lake City, Utah; the origin of the seed is unknown. Atriplex and Eriogonum plants were grown by the U. S. Forest Service Nursery from seeds we collected in the San Bernardino Mountains. Plants were removed from containers and placed in holes made with KBC bars. Living plant material was shipped from nurseries to the Big Bear District Headquarters (USFS) and held for 2 weeks to harden. During that period snow and freezing temperatures caused some damage to seedlings but all species remained alive. At planting, nightime temperatures were occasionally below freezing; snow remained in protected locations and storms were

mixtures of snow and rain.

Seed material for the lower portions of the plots were collected in the San Bernardino Mountains during the summer and fall of 1979. Samples of these seed lots were used for germination trials discussed later. The seeds were treated to induce maximum germination as determined from our experiments. All preconditioning treatments listed in Table 2 were applied immediately before planting. Water was applied to all plots within 1 hr after seeds were distributed. Where very coarse particles were near the surface, no surface manipulations beyond that described in the experimental design section was attempted. Where fine particles were near the surface, seeds were raken in along 10-20 cm wide contour terraces as described for fertilizer application.

Soil microorganisms are important in nitrogen fixation and mycorrhizal formation, and must be present for optimal response of some species (Cundell, 1977; Lindsey et al., 1977; Youngberg and Hu, 1972; Webster et al., 1967; Aldon, 1979). To assure that necessary microorganisms were present at the site, soil was collected from beneath naturally growing individuals of each species planted in May 1980 and distributed over the appropriate experimental plots.

Results and Discussion

Survival of contain species 1 year after planting is detailed in Table 3. Four months after planting the seedlings, all appeared dead but those listed recovered and were vigorous in June 1981. Eriogonum fasciculatum is the only species that did not recover. The experimental area is near the upper margin of the distribution for this species. Winter temperatures were therefore the probable cause of death. The three most successful species were Purshia

Table 2. Preconditioning treatments applied to seed material prior to planting, 22, 23 May 1980.

Species	Treatment
Fremontodendron californica	Submerged in 95°C water, and soaked while cooling for 24 hr, soaked in thiourea for 24 hr, then in 1000 ppm GA_3 for 24 hr.
Penstemon grinnellii	5 weeks stratification, then soaked for 24 hr in 1000 ppm GA_3.
Purshia glandulosa	Stratified for 4 wks.
Ceanothus greggii	Submerged in 95°C water, soaked while cooling for 24 hr, soaked in 3% thiourea for 30 hr, then in 1000 ppm GA_3 for 24 hr.
Atriplex canescens	None.
Cercocarpus ledifolius	Submerged in concentrated H_2SO_4 for 20 min, 3% thiourea for 8 hr, then soaked in 1000 ppm GA_3 for 24 hr.

Table 3. Survival (%) of containerized plants 1 year after planting; M = mulch, O = fertilizer beads, T = fertilizer tablets, W = water, C = control.

	M	M,O	O	T	C	M,W	M,W,O	W,O	W,T	W	Total
Artemisia tridentata	0	10	0	5	15	0	0	10	0	0	40
Purshia glandulosa	0	0	0	0	0	0	0	20	60	0	80
Atriplex canescens	4	0	6	6	10	10	0	4	2	2	44
Cercocarpus ledifolius	0	0	0	0	0	20	0	28	23	13	84
Chrysothamnus nauseosus	10	0	75	8	16	8	16	8	8	25	174
Eriogonum fasciculatum	0	0	0	0	0	0	0	0	0	0	0
Total	14	10	81	19	41	38	16	70	93	40	

Table 4. Average size (cm) of Chrysothamnus nauseosus and Cercocarpus ledifolius plants 1 year after planting; M = mulch, O = fertilizer beads, T = fertilizer tablets, W = water, C = control.

	M	M,O	O	T	C	M,W	M,W,O	W,O	W,T	W
Chrysothamnus nauseosus	14	-	9	8	11	8	8	14	6	12
Cercocarpus ledifolius	-	-	-	-	-	8	-	12	10	6

glandulosa, Cercocarpus ledifolius and Chrysothamnus nauseosus.

Chrysothamnus nauseosus survived under a wider variety of experimental conditions than any other species. Such a broad range of tolerance makes this a species with a great deal of promise for revegetating carbonate mines. Table 4 lists the average height of individuals on each of the experimental plots. There is no significant difference in height between plots. This suggests that this species places little demand on nutrient resources and will do well in nutrient poor areas. This species has also been successful in other studies (e.g. Lindsey et al., 1977). Rubber rabbitbrush is represented by 11 varieties in California. This is evidence of a high level of adaptability of this shrub to a wide range of environmental conditions. Careful selection of varieties adapted for specific conditions nearly assures success of revegetation projects using this species. Chrysothamnus may reach a height of 2 m and be as broad; a profusion of yellow flowers in late summer and fall make it a species worth further study.

Cercocarpus ledifolius (curlleaf mountain mahogany) was highly successful but under a much narrower range of experimental conditions than rubber rabbitbrush. The single additional watering given plants on the upper terrace was enough to allow Cercocarpus to survive. This large shrub or small tree (to 9 m) was successful on lower elevation carbonate mine studies (Burk and Hanes, 1978) and is the dominant on many calcium carbonate outcrops in the transverse mountain ranges. This species would be most effective as a revegetation component because of its large size and very dark green color. Growth of Cercocarpus (Table 4) is significantly higher ($P < .05$) when fertilized, watered plots are compared to watered plots without fertilizer. The type of fertilizer made no difference ($p > .05$) in

overall response.

Purshia glandulosa (bitterbush) did best on fertilized plots without mulch. This is a dark green shrub reaching 2-3 m in height and is common on surrounding pinyon-juniper dominated hillsides. Its overall texture and color give it high potential as revegetation species.

Atriplex canescens (four-winged saltbush) had low rates of survival but survived over a broad range of treatments. This broadly adapted plant is successful in rehabilitation studies elsewhere (e.g. Moghaddam and McKell, 1975). Survival of seedlings has been found to be sensitive to transplant size. Our plants were within the optimum ranged reported by Moghaddam and McKell, however, in another environment results may differ. This smaller, grayer plant probably has less potential for rehabilitating these sites than the other species already discussed.

Artemisia tridentata had very low survival in our experimental conditions. This combined with limited cosmetic impact of a gray shrub against light colored soil suggests that further studies on this species would not be productive for this situation.

The seed plots were not successful in 1979 and only one species established from spring 1980 plantings. Penstemon grinnellii seedlings were not visible in the planted plots following spring 1980 plantings. They presumably entered a secondary dormancy, overwintered, and germinationed by June 1981. We are confident these are the seeds we planted because of location.

Two perennial species are quite common on some study plots having come from naturally occurring seed. Penstemon grinnelli ssp. grinnellii is forming > 60% cover in limited areas. Performance does not appear to be significantly influenced by the experimental manipulations

associated with this study, although quantitavie analysis were not made. The general distribution seems related to seed availability with older more dense populations near individuals that probably survived or established shortly after the mining activities. Chrysothamnus parryi, a low (0.5-1 m) shrub is present on the site and significant expansion of the population is occurring. This species would make an excellent revegetation species for this site. Our seed collections showed no viability by the tetrazolian test so this was not included in this study. It is, however, very well adapted to the site.

Several annuals are present and reseeding the slopes including Salsola iberica (Russian thistle), Mentzelia sp., and Hordeum vulgare (barley, from the straw mulch). These provide little cover and probably reduce water and nutrients available for growth of the species more valuable for revegetation.

Mulch reduced growth and survival of most species. The literature suggests that mulch is valuable in rehabilitation of arid lands because it reduces evaporation, surface temperature of the soil, runoff, etc. (Packer and Aldon, 1978). The same result was noted with straw mulch and with redwood compost in an earlier study (Burk and Hanes, 1978). A theoretical explanation is possible although no data are available. Organic acids released from the mulch may reduce the pH sufficiently to upset the balance between exchangeable calcium, and available phosphate, potassium and iron, thus creating an imbalanced soil medium. Water definitely increases survival during the first summer. Here, a single watering 2 weeks after planting was quite effective. We believe that survival could be increased dramatically by watering containerized plantings through the first summer.

Application rates of fertilizer require further study. Our data show that growth and perhaps survival are increased by applications of fertilizer. Slow release forms are necessary because of the coarse, easily leached soil; a rapid release fertilizer would be available for only a very short time. The best results are obtained with slow release fertilizers when the soil remains relatively damp. Osmocote beads may become less available upon severe drying and Agriform pellets require bacterial breakdown, and thus moisture, to release nutrients. It may be assumed, then, that fewer nutrients are available than would be expected with comparable fertilizer application in a less arid habitat.

LABORATORY

GERMINATION TRIALS

Seeds were collected from San Bernardino Mountain plants growing in conditions similar to the mine site but not necessarily on carbonate substrate. This provided plant materials for the experimental trials that had maximum probability of tolerating environmental conditions at the mine site so that response to the unique soil conditions and to experimental conditions could be tested. Seeds of five of the species judged potentially the most successful for revegetation were subjected to a series of germination trials to establish any pretreatments necessary to assure maximum germination in the field. No attempt was made to determine natural germination requirements nor to duplicate field conditions. The goal was to obtain maximum germination in the shortest period. Thus, seeds known to require extended periods of stratification were treated chemically to reduce storage time. Germination trials were conducted for Fremontodendron californica, Penstemon grinnellii ssp. grinnellii,

Purshia glandulosa, Ceanothus greggii, and Cercocarpus ledifolius. The results are presented in Tables 5-9.

Viability tests were carried out on all test species using a 0.5% solution of 2, 3, 5-triphenyltetrazolium chloride. Seeds were cut in half and allowed to soak in the solution for 24 hours. Embryos that stained red were considered to be from viable seeds.

Pretreatment trials were carried out in the order presented in the tables. Most conditions are described in the tables; however, a few additional notes are presented here. In all cases where seeds were soaked in thiourea, soaking was followed by 1 hour of leaching in running water to remove residual chemicals that might interfere with embryo development (Hartman and Kester, 1975). When the series of pretreatments were carried out on the same sample of seeds, hormonal treatments were always applied last. Stratification was accomplished by placing seeds in washed sand at 2°C for the times specified in the tables. Prior to germination all seeds were surface sterilized by dipping in 50% household bleach solution followed by a sterile water rinse. All germination trials were conducted in petri dishes on a piece of filter paper placed over 3-4 mm of sand using sterilized equipment and materials.

Fremontodendron californica, Table 5.

Using hot water to crack the seed coats of Fremontodendron, then cooling while soaking for 24 hours as recommended by Nord (1974) and allowed the seeds to imbibe water but did not overcome internal dormancy. Initial tests with thiourea and gibberellic acid were made after scarifying the seed coat to insure imbibition of these solutions into the seed. Of these treatments a 24 hour exposure to thiourea resulted in the best germination. Similar results were obtained when

seeds were placed in hot water and allowed to soak overnight prior to being treated with thiourea. The longer exposures of 24 and 30 hours stimulated considerably higher germination. Treatment with gibberellic acid in addition to thiourea improved germination success. No differences were found for various times of exposure to thiourea. Visual inspection of these plates revealed that seedlings from the 24 hour thiourea treatment were the most vigorous.

The highest germination was obtained after heat shock and eleven weeks of stratification; 34 out of 40 seeds were found to have germinated during stratification.

Penstemon grinnellii ssp. grinnellii, Table 6

The literature indicates that seeds of Penstemon sp. required no pregermination treatments (Emery, 1964). Following this recommendation for P. grinnellii resulted in very low germination. Leaching of seeds did not sufficiently improve germination, suggesting that there was not an easily removed water soluble inhibitor involved.

In all cases where thiourea was used, even for very short exposures, it appeared to inhibit germination. Seeds treated with gibberellic acid alone or in combination with thiourea showed improved germination but results were highly variable. A short period of stratification followed by exposure to gibberellic acid resulted in higher and more reliable germination success.

Purshia glandulosa, Table 7.

In tests on Purshia tridentata conducted by other investigators, dormancy was broken using only thiourea (Evans, 1977; Pearson, 1957). Our results indicated that treatment with thiourea is only effective on mechanically scarified P. glandulosa seeds. It appears that the seed coats, although not extremely hard, prevent the imbibition

Table 5. Results of germination and viability tests on seeds of *Fremontodendron californica*.

Treatment	Germinating Conditions	Sample Size	% viable or % of viable germinating
Viability - Tetrazolium chloride		100	92
82°C Water--soak while cooling 24 hr	16 hr lt at 15°C 8 hr dk at 2°C	100	0
1000 ppm GA_3--24 hr scarified	"	30	7
2% thiourea 0.5 hr	"	30	14
1.5 hr	"	30	4
24 hr	"	50	22
95°C Water - soak while cooling 24 hr plus 3% thiourea for 12 hr	"	40	24
18	"	40	22
24	"	40	30
30	"	40	49
3% thiourea for 18 hr plus 24 hr in 1000 ppm GA_3	"	40	76
24 hr plus 24 hr in GA_3	"	40	76
30 hr plus 24 hr in GA_3	"	40	73
95°C water for 5 min plus 11 weeks stratification	"	40	92

Table 6. Results of germination and viability tests on seeds of *Penstemon grinnellii* ssp. *grinnellii*.

Treatment	Germinating Conditions	Sample Size	% viable or % of viable germinating
Viability		60	62
None	Room temperature	30	16
Leached for 46 hr	"	99	10
3% thioruea for 24 hr	16 hr lt at 15°C 8 hr dk at 2°C	50	0
1000 ppm GA_3 for 24 hr	"	30	0
3% thiourea for: 0.5 hr	"	50	0
1.5 hr	"	30	0
Leached for 24 hr plus 1000 ppm GA_3 for: 9 hr	"	50	58
24 hr		50	29
48 hr		50	39
72 hr		50	35
96 hr		50	71
Leached for 24 hr plus 1000 ppm GA_3 24 hr plus 3% thiourea for: 6 hr	"	50	29
12 hr	"	50	0
24 hr	"	50	10
30 hr	"	50	0
Stratified for: 1 wk	"	48	7
2 wk	"	50	3
3 wk	"	50	10
4 wk	"	50	29
6 wk	"	25	39
8 wk	"	24	47
18 wk	"	40	0
Stratified 6 wk plus 1000 ppm GA_3 for 24 hr	"	25	77
Stratified 8 wk plus 1000 ppm GA_3 for 24 hr	"	24	87

Table 7. Results of germination and viability tests on seeds of *Purshia glandulosa*.

Treatment	Germinating Conditions	Sample Size	% viable or % of viable germinating
Viability		100	55
None	Room Temperature	30	0
Scarified with sandpaper	"	40	0
Scarified plus -			
1000 ppm GA_3 for 72 hr	16 hr lt at 15°C 8 hr dk at 2°C	30	0
3 % thiourea for 24 hr	"	50	73
1000 ppm GA_3 for 24 hr	"	30	24
3% thiourea for: 0.5 hr	"	30	0
1.5 hr	"	30	0
Leached for 24 hr plus 1000 ppm GA_3 for 24 hr plus:			
3% thiourea for: 14 hr	"	30	12
18 hr	"	30	0
20 hr	"	30	24
95°C H_2O - soak while cooling 24 hrs plus			
3% thiourea for: 24 hr	"	60	0
Concentrated H_2SO_4 for:			
5 min	"	30	12
15 min	"	30	24
30 min	"	30	18
45 min	"	30	18
Stratified for: 1 wk	"	30	0
2 wk	"	30	12
3 wk	"	30	18
4 wk	"	30	79
7 wk	"	30	91

of water and chemical solutions. Neither hot water nor exposure to concentrated sulfuric acid sufficiently scarified the seeds.

Dormancy was reduced through stratification and seeds became more permeable with better germination and more vigorous seedlings than for those scarified and treated with thiourea.

Ceanothus greggii, Table 8.

According to the literature, good germination success can be obtained for most Ceanothus species by stratification after scarification (Reed, 1976). With this in mind an attempt was made to overcome dormancy using chemical treatments and thus reduce the necessary treatment period.

Initial tests using thiourea and gibberellic acid indicated that exposure to these chemicals inhibited germination. Scarification alone resulted in higher germination than treatment with either chemical alone. Combinations of hot water, 3% thiourea, and GA_3 satisfactorily increased germination.

Cercocarpus ledifolius, Table 9.

Pretreatments found successful by other investigators proved to be only marginally satisfactory in breaking the dormancy of the seeds being tested here. Exposing achenes to low concentrations of KNO_3 and 1000 ppm gibberellic acid at 5°C for three weeks as suggested by Young et al. (1978) resulted in minimal success (Chamberlain, 1979). Germination after stratification was fair although not nearly as good as that indicated by Deitschman et al. (1974). Deitschman et al. also stated that exposure to concentrated sulfuric acid followed by thiourea would succeed in breaking dormancy. This procedure resulted in about 50% germination in our seeds.

Table 8. Results of germination and viability tests on seeds of *Ceanothus greggii*.

Treatment	Germinating Conditions	Sample Size	% viable or % of viable germinating
Viability		40	65
95°C H_2O soak, cool 24 hrs plus 3% thiourea for: 12 hr	16 hr lt at 15°C 8 hr dk at 2°C	40	12
18 hr	"	40	35
24 hr	"	40	12
30 hr	"	40	42
Scarified with dental drill	"	39	51
Scarified plus:			
1000 ppm GA_3 for 24 hr	"	38	0
3% thiourea for 18 hr	"	40	12
95°C H_2O soak, cool for 24 hr plus 1000 ppm GA_3 plus 3% thiourea for:			
30 hr	"	40	96
36 hr	"	40	85
42 hr	"	40	89
Boiling H_2O for 1 min, cooled for 30 min plus 1000 ppm GA_3 for 36 hr plus 3% thiourea for: 30 hr	"	40	42
36 hr	"	40	85
42 hr	"	40	46
Boiling H_2O for 1 min, cooled for 30 min plus 3% thiourea for 1 hr plus 1000 ppm GA_3 for: 2 hr	"	40	77
6 hr	"	40	27
9 hr	"	40	19
95°C H_2O and soak while cooling for 24 hr plus 7 wk stratification	"	40	85

Table 9. Results of germination and viability tests on seeds of *Cercarpus ledifolius*.

Treatment	Germinating Conditions	Sample Size	% viable or % of viable germinating
Viability		100	68
None	16 hr lt at 15°C 8 hr dk at 2°C	40	0
Concentrated H_2SO_4 for 20 min plus 3% thiourea for: 8 hr	"	40	55
16 hr	"	40	22
24 hr	"	40	0
Concentrated H_2SO_4 for: 1 min	"	40	0
2.5 min	"	40	0
5 min	"	40	0
10 min	"	40	7
22 min	"	40	22
30 min	"	40	48
95°C water and soak while cooling for 24 hr	"	40	0
95°C water and soak while cooling for 24 hr plus 3% thiourea for: 18 hr	"	40	0
24 hr	"	40	0
30 hr	"	40	0
Scarified with sandpaper	"	40	0
Scarified with sandpaper plus 3% thiourea for: 18 hr	"	40	0
24 hr	"	40	0
30 hr	"	40	0
Concentrated H_2SO_4 for 30 min plus 3% thiourea for: 2 hr	"	40	7
4 hr	"	40	22
8 hr	"	40	15
12 hr	"	40	11
16 hr	"	40	18

Table 9 (Continued)

Treatment	Germinating Conditions	Sample Size	% viable or % of viable germinating
Concentrated H_2SO_4 for 30 min plus 1000 ppm GA_3 for 24 hr	16 hr lt at 15°C 8 hr dk at 2°C	40	15
Concentrated H_2SO_4 for 30 min plus 3% thiourea for 20 hr	"	40	29
Concentrated H_2SO_4 for 30 min plus 3% KNO_3 for: 24 hr	"	40	7
30 hr	"	40	7
Concentrated H_2SO_4 for 30 min plus 1000 ppm GA_3 for 24 hr plus 3% KNO_3 for: 12 hr	"	40	37
24 hr	"	40	15
30 hr	"	40	7
Boiling water for 1 min plus 3% KNO_3 for 12 hr	"	40	37
Concentrated H_2SO_4 for 20 min plus 3% thiourea for 8 hr plus 1000 ppm GA_3 for 24 hr plus 3% KNO_3 for: 2 hr	"	40	40
6 hr	"	40	40
18 hr	"	40	11
Stratified 4 wk	"	20	52
7 wk	"	40	33

The achenes of Cercocarpus ledifolius appear to be only slightly permeable to aqueous solutions. Seeds did not show signs of imbibing water unless they were stratified, soaked in solutions for extended periods of time, or first exposed to concentrated sulfuric acid. Sulfuric acid treatment gave highly variable results. Attempts to render seeds permeable using either hot water or scarification with sandpaper failed. The only treatment besides sulfuric acid which showed some promise was the boiling of seeds in water for one minute. This, in combination with chemical treatments, deserves further investigation.

RECOMMENDATIONS

Our studies suggest that revegetation after calcium carbonate mining can be accomplished at relatively low cost and high success. The soils are not toxic nor do they have severe nutrient imbalance for particular species of plants. The natural succession of plants on these sites would likely take several hundred years. However, by proper cultural techniques, the plants that would dominate the site naturally can be encouraged and rehabilitation time reduced to a few decades. We are able, then, to take advantage of new concepts of succession which show that it is not necessary for earlier stages in succession to occur before the climax species can succeed.

Topography

Mining activities should include returning the physiography to a form compatible with the surrounding landscape and maintaining access for necessary revegetation activities. Mining on the desert slopes of the transverse mountain ranges in southern California should limit the height of highwalls to 6-7 m. This is the maximum height

of trees well adapted to these sites. Fine material (i.e. less than 2 mm particle size) should cover all slopes and terraces. For revegetation purposes, only enough material to fill the voids between boulders left from mining is necessary. Top soil present before mining should be removed, stored and utilized as fine material for recovering the site. If sufficient topsoil is not available to cover the entire site, finely crushed carbonate rock can be used. This material is not toxic and will support the growth of selected plant species.

Microtopography

Prior to planting all slopes should be imprinted on the contour to increase rainwater infiltration and reduce erosion. This is important because the carbonate fines tend to harden after wetting, thus severely reducing infiltration on slopes. Where topsoil is replaced, this will also reduce erosion.

Planting

Plants should be containerized. Containerized plants have a much better chance of survival than do seeds and specific placement of water and fertilizer made possible by using containerized plants is more economical and efficient. Complete fertilizer should be added in a slow release form in the vicinity of each plant. Fertilizers that contain a variety of micronutrients, especially iron, would be of the greatest benefit. Mulch, organic soil amendments or anything that will decrease pH should be avoided. Lower pH increases nutrient imbalance and inhibits growth and survival. Planting should be done in late spring while nightime temperatures are near or below freezing and snow storms still possible. Plants

should be watered at planting time and every 2 weeks thereafter for the duration of the first summer. Watering during the second summer would probably increase growth but probably not survival.

Plant Materials

Three of the species reported on here will adequately serve to revegetate these sites. These include Cercocarpus ledifolius, Chrysothamnus nauseosus, and Purshia glandulosa. Additional species judged to have high potential, although no studies have been conducted, are Chrysothamnus parryi, Pinus monophylla, Fremontodendron californica, and Juniperus californica. Pinus monophylla and Cercocarpus ledifolius are tallest and should be used on terraces in front of highwalls. Seeds for propagation of plants should be obtained from local populations growing on limestone outcrops when possible.

Further research

The success of revegetation studies using the materials and techniques suggested here could be enhanced by confirming the appropriateness of Pinus monophylla, Fremontodendron californica, and Juniperus californica by running trials with containerized seedlings. Additionally, fertilizer availability and application rates should be studied so that growth rates are maximized and rehabilitation time shortened.

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